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MEMORANDUM REPORT NO. 2156

MEASURING 557.7 NM AIRGLOW CHANGES ASSOCIATED WITH
UPPER ATMOSPHERIC ION CLOUD RELEASES.

by

Aivars Ozolins

March 1972

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MARCH 1972

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Aivars Ozolins

Signature and Propagation Laboratory

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RDTE Project No. 1T061102B53A-15

ABERDEEN PROVING GROUND, MARYLAND

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

| | |
|--|--|
| 1. ORIGINATING ACTIVITY (Corporate author) US Army Aberdeen Research and Development Center Ballistic Research Laboratories Aberdeen Proving Ground, MD 21005 | 2a. REPORT SECURITY CLASSIFICATION Unclassified |
| | 2b. GROUP |

3. REPORT TITLE

MEASURING 557.7 NM AIRGLOW CHANGES ASSOCIATED WITH UPPER ATMOSPHERIC ION CLOUD RELEASES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Aivars Ozolins

6. REPORT DATE

March 1972

7a. TOTAL NO. OF PAGES

21

7b. NO. OF REFS

13

8a. CONTRACT OR GRANT NO.

6. PROJECT NO. RDTE 1T061102B53A-15

8a. ORIGINATOR'S REPORT NUMBER(S)

BRL Memorandum Report No. 2156

c.

d.

9d. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

US Army Materiel Command
Washington, DC 20315

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On two of the events a strong signal was recorded at 557.0 nm. The identity of this signal which appeared about 10 min after release time has not been established.

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OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

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Security Classification

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|--------|----|--------|----|--------|----|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Airglow Upper Atmosphere Barium Clouds Twilight Spectrophotometry | | | | | | |

2a

Unclassified
Security Classification

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Aberdeen Proving Ground, Md.
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I. INTRODUCTION

According to a paper by Haerendel, Lüst, and Rieger,^{1*} the motions, expansions, and distortions of artificial upper atmospheric ion clouds cannot be properly understood without considering the effects of a charge transport coupling between the clouds and the atmospheric E and F regions. Stoffregen² found supporting evidence for the proposed coupling by recording 4-to-10 percent airglow intensity variations at 557.7 nm with about 1 min duration times after cloud release. Airglow changes are to be expected since theory calls for E-layer electron density variations within the magnetic shadow area of the ion clouds.

An experiment similiar to Stoffregen's was set up for the SECEDE II tests in Florida during January and February of 1971 to verify and calibrate the airglow effect. Due to the large twilight background that was present at release time it was not possible to obtain airglow data of sufficient quality to detect variations of the size reported by Stoffregen. After the tests, an analysis was made on the field data to determine the measurement limitations imposed by the adverse conditions encountered. These limitations were then applied to several optical instruments to optimize their performance for measurements of the type described. The first half of this report gives a brief summary of the SECEDE II tests and the second half gives the results of the performance study.

II. SECEDE II FIELD MEASUREMENTS

A tilting filter photometer, a nontilting photometer, and a pressure scanning Fabry-Perot interferometer were used during the SECEDE II airglow tests. The optical layouts for these are given in Figures 1 through 3. The operation of tilting filter instruments is covered in Reference 3 and

*References may be found on page 16.

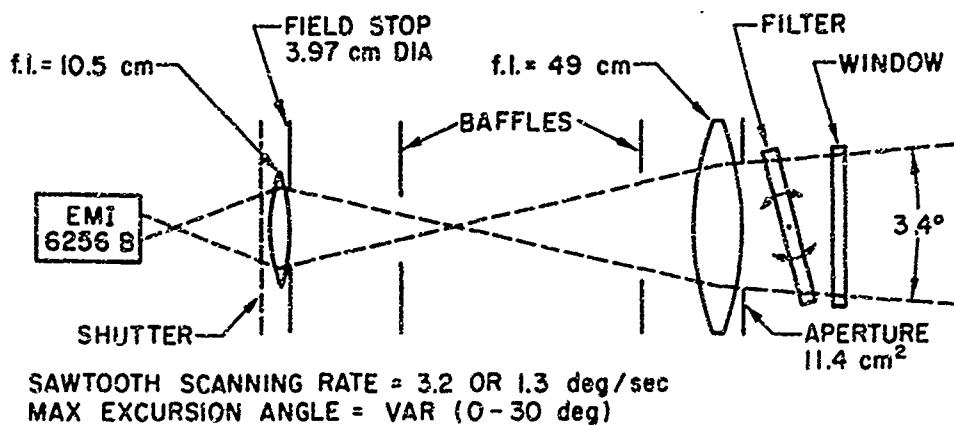


Figure 1. Tilting Photometer Optical Layout

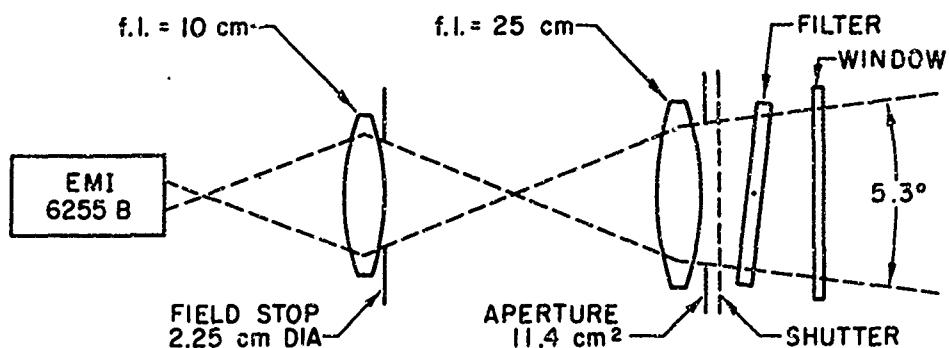


Figure 2. Non-Tilting Photometer Optical Layout

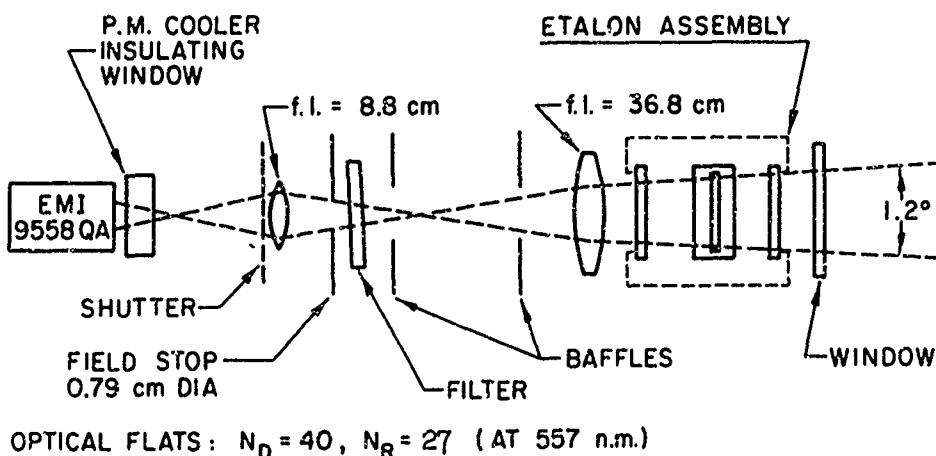


Figure 3. Fabry-Perot Interferometer Optical Layout

Fabry-Perot type instruments in References 4 and 5. Sixty-millimeter optical plates were used in the interferometer. These were flat to $\lambda/80$ (limiting finesse $N_d = 40$) and had reflectivities of 89 percent at 558 nm (reflecting finesse $N_r = 27$).*

Tilting Photometer Data

Data were taken with this instrument for three events. In each case the twilight continuum (background) radiation was too intense to detect the comparatively weak 557.7 nm airglow line at the time of cloud release. Signal-to-background (S/B) ratios were later determined to have been between 0.005 to 0.02.

After cloud formation, the instruments were kept operating until nighttime conditions prevailed. On two of the events progressively severe optical interference was recorded as the position of the drifting neutral cloud approached the photometer's line of sight. The characteristics of the interference were a temporary enhancement of the background (by as much as a factor of 2) and the appearance of two spectral lines. One of these emissions was readily identified as the 553.5 nm resonance line of neutral barium. The other line has not, as yet, been identified.

The recorded wavelength of the unknown feature is 557.0 ± 0.2 nm. No barium cloud or airglow lines listed in the literature correspond to this value.^{6,7} Some doubt exists, however, whether the recorded wavelength is correct. This uncertainty is due to the recorded halfwidth of the feature being considerably less than the 1.8 nm transmission halfwidth of the interference filter that was used.

A narrow signal, such as was observed, can possibly be explained as due to second order transmission effects. A study of the filter wings verified that the filter does, in fact, have a small but suitably narrow secondary transmission peak near 278.5 nm (half of the recorded wavelength). In addition, the MIT wavelength tables⁸ give 278.5 nm as the wavelength of a nonresonance barium emission line.

*Overall finesse gives the maximum number of spectral elements that can be measured (resolving power per unit interference order). This value depends on plate flatness, reflectivity, scanning aperture size, and plate alignment. The effect of these factors can be separated and separate finesses such as N_d and N_r above can be assigned to them.

A definitive experimental test to determine the likelihood of having detected the barium line in question would be to compare the SECEDE data with the response of the photometer to a barium lamp emitting that line. No suitable lamps were readily available at this laboratory. A less definitive test, however, was attempted by illuminating the photometer with the output beam of a 1/2m Ebert monochromator set at 278.5 nm. The response of the photometer to this imitation line source failed to satisfactorily duplicate the field data characteristics of the unidentified line.

The possibility of stray light reaching the detector from outside the field of view was also considered. No obvious way for this to occur was discovered, but this possibility cannot be entirely ruled out.

If the unidentified emission line (recorded on two separate occasions) was genuine, its presence may have some significance to barium cloud chemistry.

Figure 4 gives early and late time data for event Pium using repeated scans from 558 to 540 nm. The late time data show typical nighttime response of the tilting photometer to the ever present 546.1 nm Hg line (scattered city lights) and the 557.7 nm green airglow line. The early data show the Hg line and the two neutral cloud emissions shortly after the time of the clouds closest approach to the line of sight. The airglow line is probably present but is obscured by the much stronger unknown emission line.

Interferometer Data

When operated with a 1.0 nm bandpass filter, a free spectral range of 0.3 nm, and an overall finesse of 7, the effective transmission bandwidth of the interferometer was about 0.15 nm (12 times smaller than the tilting filter system). This produced larger S/B values. The luminosity or throughput, however, was 8 times lower. As a result, the interferometer produced only marginally better signal-to-noise (S/N) values at release time.

Figure 5 gives early and late time data for event Spruce. The late time data show the interferometer response to the nighttime airglow when no excess background radiation was present. The early data show the response 7 min before cloud release, the background then being 650 times more intense. The 10 percent variation in the early data cannot be interpreted as due to the green line which should have comprised about 1 percent of the recorded signal. Instead it appears to be due to spectral intensity variations in the twilight continuum near 558 nm. This conclusion is supported by the fact that the variation halfwidth is much greater than the airglow halfwidth in the late data and because the variation intensity was proportional to the decreasing background signal for more than two orders of magnitude.

Nontilting Photometer Data

This instrument was used for the first two events as an auxiliary monitor of the 553.5 nm barium line. Neutral cloud interference, recorded with the tilting photometer, was also detected with this instrument.

For the last two events the output of the nontilting photometer was amplified, inverted, and mixed with the output of the Fabry-Perot providing, in effect, a variable zero suppression control - the suppression being proportional to the rapidly changing background intensity. This method of eliminating the unwanted background component from the overall signal worked well in practice. A slight degradation in the S/N ratio from mixing the two signals, however, was unavoidable (in this case of no consequence since too much noise was already present). Refinements of this technique using synchronous (phase-locked) detection will be discussed in the next section.

III. PERFORMANCE STUDY RESULTS

The low S/B and S/N values of the data taken indicated the need for instruments with better background rejection and greater sensitivity. On the basis of high luminosity to effective passband ($L/\Delta\lambda$) ratios^{3,9,11} three spectrophotometers were chosen for consideration as being most

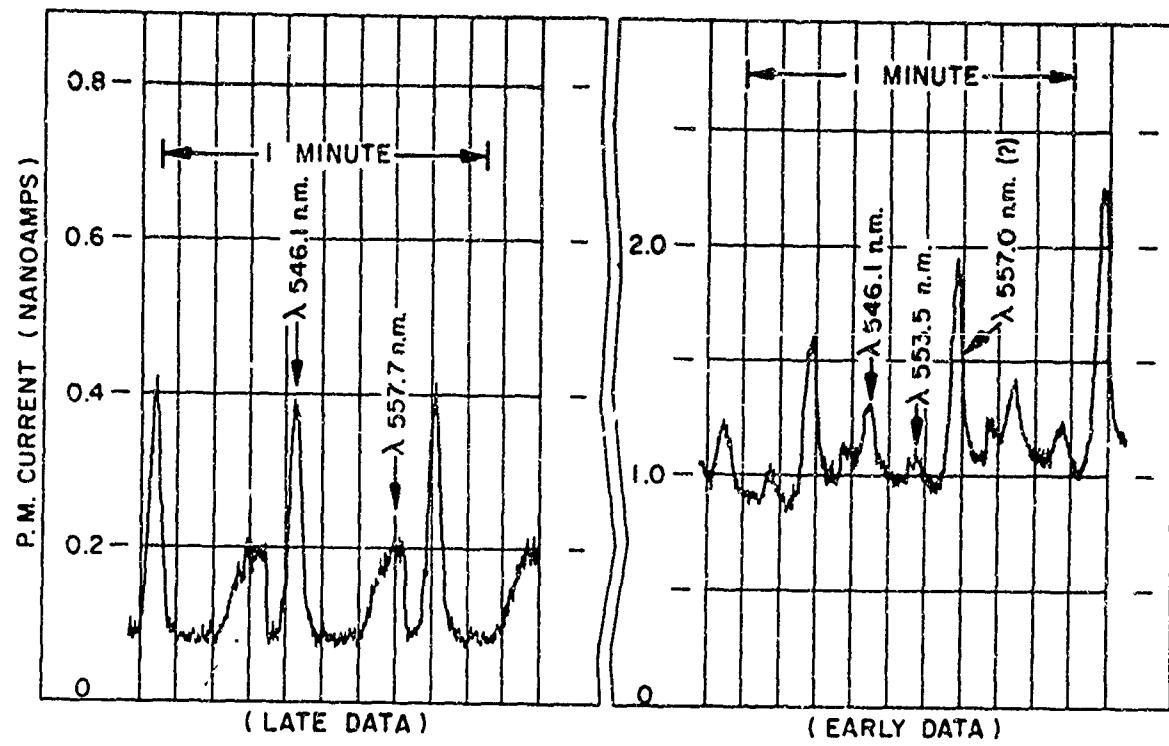


Figure 4. Tilting Photometer Data, Event Plum. Early Data at Barium Release Time + 12 Mins., Late Data at Release Time + 30 Mins.

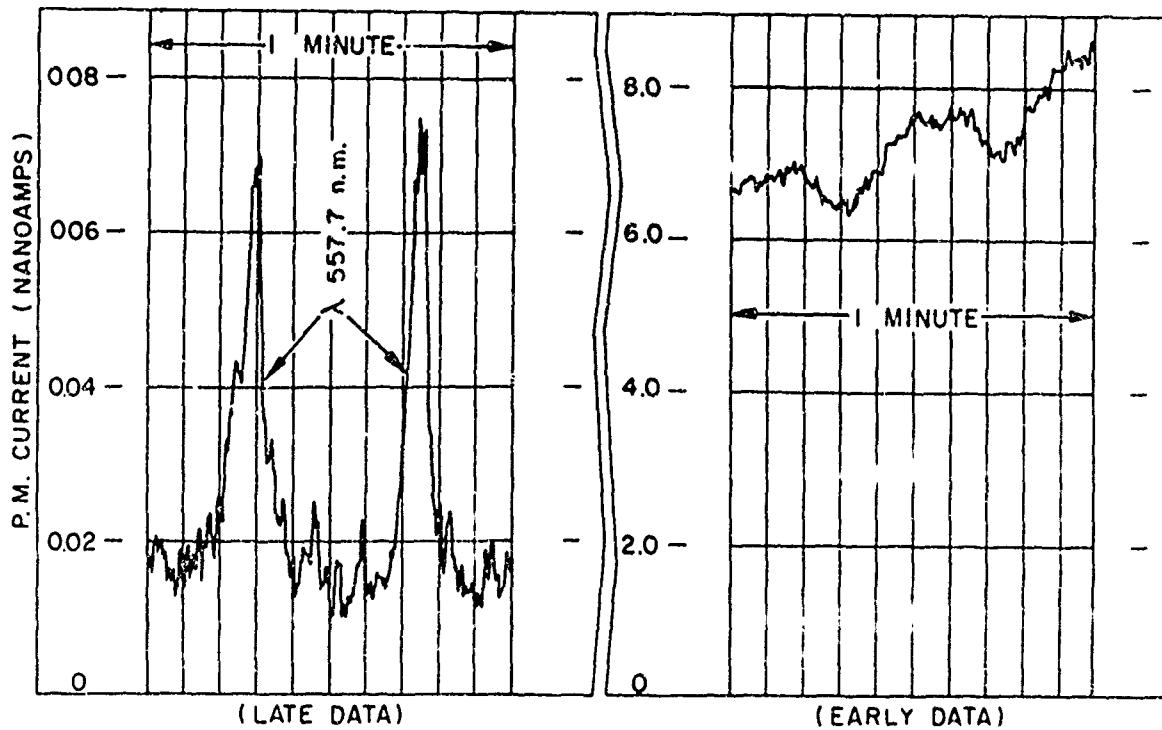


Figure 5. Interferometer Data, Event Spruce. Early Data at Barium Release Time — 7 mins., Late Data at Release Time + 32 Mins.

suitable for SECEDE II type airglow measurements. This selection criterion is useful when background shot noise dominates other forms of noise in the recorded signal. The S/N ratio is then directly proportional to $(L/\Delta\lambda)^{1/2}$ where, by definition,

$$L = A\Omega\tau_0$$

and

$$\Delta\lambda = \int_{\lambda} \tau(\lambda)/\tau_0 d\lambda .$$

A is the cross-sectional area, Ω is the solid angle (field of view) of the beam inside the instrument, and $\tau(\lambda)$ is the spectral transmittance with peak value τ_0 .

To predict and optimize their performance, parametric studies were done on each of the selected instruments. The results of these studies, given in the Table, are based on the following conditions:

- (1) 557.7 nm airglow brightness = 150 rayleighs (1 rayleigh = 4π megaphotons/cm²-sec-ster)
- (2) background brightness = 10^4 rayleighs/nm
- (3) effective detector quantum efficiency = 9.4 percent (S-20 response with a 75 percent collection efficiency¹²)
- (4) measurement bandwidth $\Delta f = 0.125$ Hz
- (5) field of view $<2.2 \times 10^{-3}$ ster (full cone angle <3 degrees). *

Conditions 1-4 were chosen from SECEDE II data as representing a realistic worst case situation. Condition 5 limits spatial resolution to dimensions less than the size of moderately small (6 km) clouds projected to the E-layer at an altitude of 100 km.

IV. DISCUSSION AND CONCLUSIONS

To detect a 4 percent change in airglow intensity a S/N ratio ≥ 25 is necessary. For dc detection this limit is satisfied by all the instruments in the Table. The S/B ratios, however, are unacceptably low,

* The inherent luminosity of a Girard grille spectrometer is substantially greater than that of any of the instruments chosen for this study.¹¹ The 3 degree cone angle restriction, however, put it at a disadvantage with respect to the other instruments and it was, therefore, not considered.

Table of Predicted Performance of Several Airglow Spectrophotometers

| Instrument | A (cm ²) | Ω (ster) | τ_0 (%) | $\Delta\lambda$ (nm) | S/B (%) | S/N* (dc mode) | S/N (syn mode) |
|---|-------------------------|----------------------|-----------------|-------------------------|------------|-------------------|-------------------|
| Filter Photometer (2 in. diam, 0.3 nm filter) | 11.5 | 2.2×10^{-3} | 35 | 0.3 | 4.7 | 41 | 21 |
| Filter Photometer (0.3 nm filter array) | 120 | 2.2×10^{-3} | 35 | 0.3 | 4.7 | 132 | 66 |
| Filter Photometer (6 in. diam, 1.0 nm filter) | 150 | 2.2×10^{-3} | 35 | 1.0 | 1.5 | 83 | 42 |
| Fabry-Perot Interferometer *(2.36 in. diam plates & 0.3 nm filter) | 23 | 4.2×10^{-4} | 26 | 0.1 | 18 | 38 | 19 |
| Fabry-Perot Interferometer (4 in. diam plates & 0.3 nm filter) | 75 | 4.2×10^{-4} | 26 | 0.1 | 18 | 68 | 34 |
| Birefringent Filter Photometer *** (6 in. diam, 1.0 nm filter) | 150 | 2.2×10^{-3} | 17 | 0.5 | 33 | - | 38 |

* S/N based on photomultiplier evaluation methods of Robben. 13

** Interferometer values are based on the following: free spectral range = 0.3 nm, plate (limiting) finesse = 40.0, reflecting finesse = aperture finesse = 8.0.

*** Operation of a birefringent filter photometer is given in References 9 and 10. The S/N value shown here is based on a 0.5 nm channel separation. The S/B value assumes a 90 percent modulation efficiency and a 5 percent continuum chop.

especially for the filter photometers. By modulating the airglow signal and recovering the ac components or by using synchronous detection the unwanted background could be eliminated. These methods utilize only 50 percent of the available signal, however, and, since the dominant background noise would remain unaffected, the S/N ratios would suffer a 2-to-1 reduction. According to the last column in the Table the small aperture filter photometer and Fabry-Perot interferometer would then be unacceptable.

Of the remaining options in the last column synchronous detection is best suited for the birefringent filter photometer - line modulation being achieved by simple rotation of a Polaroid plate. The attainable S/N ratio of 40 would be sufficient for measuring the small airglow changes associated with artificial ion cloud releases.

Synchronous detection for the large interferometer need not be seriously considered. Modulation of the airglow line at narrow plate separations could be difficult to implement and the attainable S/N ratio would not be better than that of the birefringent photometer anyway unless larger and more costly interferometer plates were used.

Less objectionable would be synchronous detection for the filter photometers. Direct oscillation of the filter or filter assembly would be acceptable although the cycling rate would be restricted to rather low values. A more attractive method that avoids this limitation would be to use a dual beam photometer with alternate sampling - one beam being tuned to the airglow line and the other to a nearby wavelength that sees only the background. Another possibility would be to have a dual instrument look at adjacent, nonoverlapping areas of the sky, one of which would coincide with the E-layer supposedly affected by the ion cloud magnetically up-range from it. The recorded signal in that case could be made to correspond directly to the airglow change within the affected region. Limiting information on the size of that region could also be obtained.

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